

Large-Scale Structures Behind the Southern Milky Way from Observations of Partially Obscured Galaxies

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Abstract

We report here on extragalactic large-scale structures uncovered by a deep optical survey for galaxies behind the southern Milky Way. Systematic visual inspection of the ESO/SRC-survey revealed over 10000 previously unknown galaxies in the region $265^\circ \lesssim \ell \lesssim 340^\circ$, $|b| \lesssim 10^\circ$. With subsequently obtained redshifts of more than 10% of these galaxies, new structures across the Milky Way are unveiled, such as a filament at $v \sim 2500 \text{ km s}^{-1}$ connecting to the Hydra and Antlia clusters, a shallow extended supercluster in Vela ($\sim 6000 \text{ km s}^{-1}$), and a nearby (4882 km s^{-1}), very massive ($\mathcal{M} \sim 2 - 5 \cdot 10^{15} \mathcal{M}_\odot$), rich Coma-like cluster which seems to constitute the previously unidentified center of the Great Attractor.

The innermost part of the Milky Way where the foreground obscuration in the blue is $A_B \gtrsim 5^m$, respectively H I-column densities $N_{\text{HI}} \gtrsim 6 \cdot 10^{21} \text{ cm}^{-2}$ remains fully opaque. In this approximately 8° wide strip, the forthcoming blind H I-survey with the multi-beam system at Parkes will provide the only tool to unveil this part of the extragalactic sky.

Keywords: galaxies: distances and redshifts - large-scale structure of Universe - surveys

1 Introduction

The Milky Way obscures about 25% of the extragalactic sky. This severely constrains studies of:

- Large-scale structures, particularly the connectivity of the Supergalactic Plane, other super-clusters, walls and voids across the Milky Way.
- The origin of the peculiar motion of the Local Group (LG) with respect to the Cosmic Microwave Background Radiation (CMB). Can the dipole in the CMB be explained by the gravity of the irregular mass/galaxy distribution in the whole sky?
- Other streaming motions. Is the predicted mass overdensity, the Great Attractor (GA) – as evidenced in a large-scale systematic flow of galaxies towards $(\ell, b, v) \sim (320^\circ, 0^\circ, 4500 \text{ km s}^{-1})$ (Kolatt et al. 1995) – in the form of galaxies, hence does light trace mass?

- Individual nearby galaxies. Could a nearby Andromeda-like galaxy lie hidden in the Zone of Avoidance (ZOA) – important for the internal dynamics of the LG, as well as mass derivations of the LG and the present density of the Universe from timing arguments (Peebles 1994). Moreover, the gravitational attraction of the nearest galaxies ($v < 300 \text{ km s}^{-1}$) generate 20% of the total dipole moment (Kraan-Korteweg 1989).

In recent years various groups have initiated projects to unveil the galaxy distribution behind our Milky Way. The methods are manifold (*cf.*, *Unveiling of Large-Scale Structures behind the Milky Way*, 1994, for a review). Here, we describe the results from a deep optical survey for galaxies in the southern Milky Way, a particularly interesting region because of the dipole in the CMB and the infall into the GA both of which point close to the southern Galactic Plane (*cf.*, Fig. 1).

2 A Deep Optical Galaxy Search in the Southern ZOA

To reduce the $\sim 20^\circ$ -wide strip of the ZOA, we have embarked on a deep search for partially obscured galaxies, *i.e.*, down to fainter magnitudes and smaller dimensions compared to existing catalogues. To date, 50 fields of the ESO/SRC-survey have been visually inspected. The surveyed area lies within $265^\circ \lesssim \ell \lesssim 340^\circ$, $|b| \lesssim 10^\circ$ – its borders are outlined in Fig. 1. Within the surveyed area of $\sim 1200 \square^\circ$, 10276 new galaxies with $D \geq 0'2$ have been identified in addition to the 269 Lauberts galaxies with $D \geq 1'$ within this area (Lauberts 1982). Their distributions are displayed in Fig. 1. Details on the search can be found in Kraan-Korteweg & Woudt 1994.

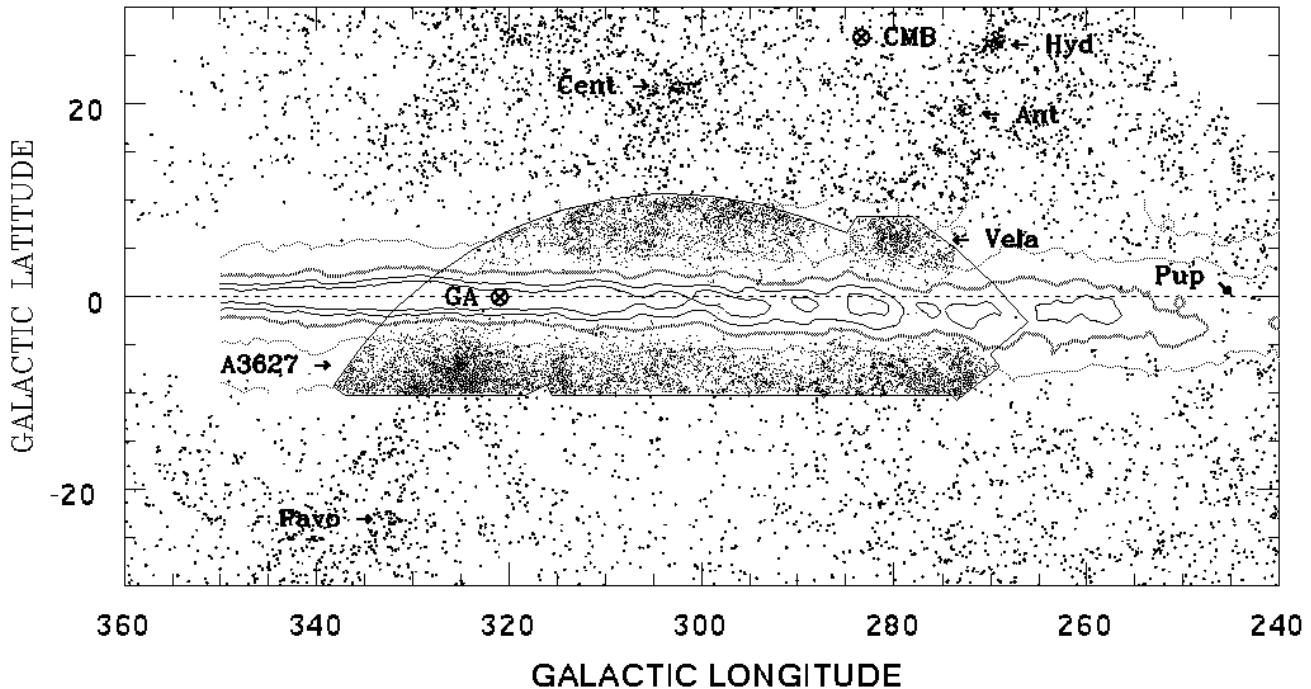


Figure 1: The galaxy distribution from our deep galaxy search ($D \geq 0'2$) and the Lauberts galaxies ($D \geq 1'$) in Galactic coordinates. The to date surveyed region is outlined. The dipole direction in the CMB, the center of the GA and the most prominent clusters are marked. The contours mark absorption in the blue of $A_B = 1^m, 2^m 5, 5^m$ (thick contour), $7^m 5, 10^m$ as derived from the Galactic HI (Kerr *et al.* 1986), adopting a constant gas-to-dust ratio and the formalism given by Burstein & Heiles 1982.

In the mean, the galaxy density is well correlated with the foreground extinction A_B as traced by the HI-column-density: for $A_B \gtrsim 5^{\text{m}}$ (thick contour), respectively $N_{\text{HI}} \gtrsim 6 \cdot 10^{21} \text{ cm}^{-2}$, the ZOA remains opaque. Above this band, distinct filaments and round concentrations uncorrelated with the foreground dust can be recognized, thus they must have their origin in extragalactic large-scale structures. Some of these features seem to align with the known galaxy distribution, as *e.g.*, a filament above the Galactic Plane which points toward the Centaurus cluster, and the filament from the Hydra and Antlia clusters towards the prominent overdensity in Vela. A significant overdensity, centered on the previously identified cluster A3627 (Abell *et al.* 1989), is evident within only a few degrees of the predicted center of the GA. It is the only Abell cluster behind the Milky Way, classified as rich and nearby and lies within the GA region. Even so, this cluster has received little attention because of the diminishing effects of the foreground obscuration. And this cluster at $(\ell, b) = (325^{\circ}, -7^{\circ})$ is hardly obvious in the distribution of Lauberts galaxies and not at all in IRAS samples. However, the galaxies in this overdensity are on average relatively large (just *below* the diameter limit of Lauberts). Lifting the obscuring veil of the Milky Way by correcting the observed properties of the galaxies for the foreground extinction would, in fact, reveal this cluster as the most prominent overdensity in the southern sky.

Redshift measurements are required to map the galaxies in 3 dimensions. The 2-dimensional galaxy distribution alone can be misleading. For instance, the prominent overdensity in Vela was found to be due to a superposition of a nearby ($\sim 2500 \text{ km s}^{-1}$) filament connecting to Hydra, a more distant (6000 km s^{-1}) shallow extended supercluster, and a very distant ($\sim 16000 \text{ km s}^{-1}$) wall-like structure crossing the ZOA (Kraan-Korteweg *et al.* 1994).

3 HI-Observations of Obscured Galaxies at Parkes

The redshifts of the uncovered galaxies are obtained by three observational approaches: (a) multifiber spectroscopy with OPTOPUS and MEFOS at the 3.6m telescope of ESO in the densest regions, (b) individual spectroscopy of the brightest galaxies with the 1.9m telescope of the SAAO, and (c) 21cm observations of extended low surface-brightness (LSB) spirals with the 64m Parkes radio telescope. So far we have obtained 1083 new redshifts in our search area.

An extensive discussion of methods and typical results are given in Kraan-Korteweg *et al.* 1994. The three observing methods are complementary in galaxy populations, characteristic magnitude and diameter range and the depth of volume they probe. The multifiber spectroscopy gives a good description of clusters and dense groups in the ZOA and traces large-scale structures out to recession velocities of 25000 km s^{-1} . The SAAO and HI-observations cover the bright end of the galaxy distribution and provide a more homogenous sampling of galaxies out to 10000 km s^{-1} .

Our HI-observations at Parkes have similar sensitivities as the forthcoming blind HI-survey with the multi-beam (MB) receiver in the ZOA and therefore merit a more detailed description. These observations are vital in recovering an important fraction of the nearby spiral galaxy population which would otherwise be impossible to map. Although we aimed at complete coverage for the brightest galaxies with the optical spectroscopy, a significant fraction of apparent bright galaxies cannot be traced in this manner. In general, this concerns nearby spirals (and also dwarfs) which – seen through a layer of extinction – are extended, very LSB objects.

We have so far observed 345 spiral galaxies without previous redshift estimates at Parkes. Each galaxy was observed in total power mode, a bandwidth of 32 MHz and the 1024 channel autocorrelator. We generally integrated 30 minutes ON / 30 minutes OFF source. This yielded an r.m.s. after Hanning smoothing of typically 4 mJy – hence comparable in sensitivity to the proposed MB ZOA-survey. However, we often detected strong galaxies in as little as ten minutes.

On the other hand, we sometimes observed a source for an hour to get sufficient signal to noise. We found the sensitivity during the day to be significantly degraded compared to the level achieved at night due to high-amplitude standing waves in the spectrum which precluded detections even with a large number of very short integrations.

In 1993 we generally centered the recession velocity at 3000 km s^{-1} and reobserved some of the non-detections at a central velocity of 7500 km s^{-1} in a second step. This resulted in a detection rate of over 50%. In 1994 and 1995, we used two IF's and offset 512 channels of each polarization by 22 MHz. This resulted in a velocity coverage of $0\text{--}10000 \text{ km s}^{-1}$ with the 32 MHz in one integration. Although the lower frequencies were often badly disturbed by interference around 8300 km s^{-1} (cf., Fig. 2), this increased our detection rate to nearly 80% in 94! Our observations were considerably less effective in the 95-run due to a strong increase in recurring interference, part of which were generated locally by the then ongoing tests of the pulsar equipment – a problem that demands careful investigation of the Galactic pulsar-survey which will be piggy-backed on the MB ZOA-survey!

A few examples of typical HI-spectra, recurring interference as well as detections at low Galactic latitudes are illustrated in Fig. 2. Panel *a* and *b* are pointed observations in the Hydra/Antlia

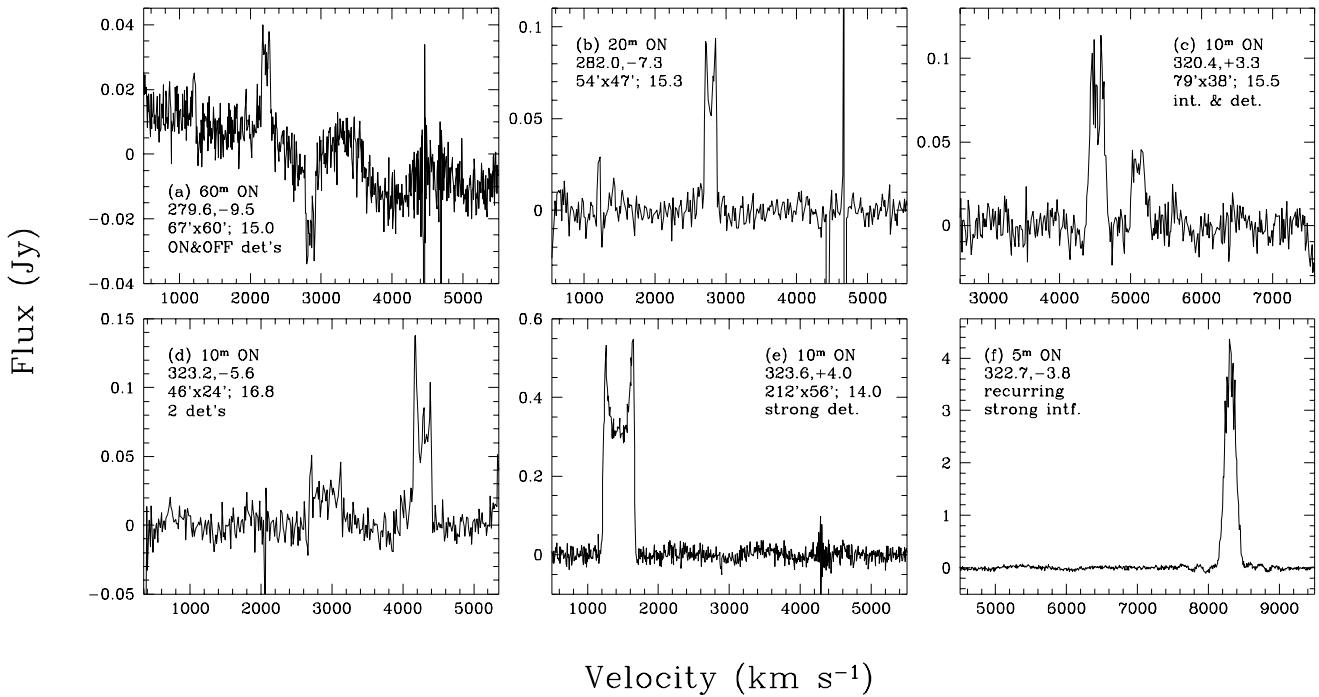


Figure 2: Typical spectra of galaxies in the ZOA obtained with the 64m Parkes radiotelescope. Integration times (between 5^{min} and 60^{min}), Galactic coordinates, observed (absorbed) diameters (in arcsec) and magnitudes in the blue B_J are indicated. Except for panel *a*, all spectra are baseline-subtracted. Regularly appearing interference of different strengths are found at 1200 , 4450 , 4700 and 8300 km s^{-1} .

extension, *c* - *f* are observations in the GA region. Panel *a* shows a detection in the ON as well as a detection in the adjacent $10^{\text{m}}5$ earlier OFF-position in the crowded nearby Hydra/Antlia-filament. Panel *b* shows another example of a previously unidentified LSB member of this filament. Note the recurring interference at 1200 , 4450 and 4700 km s^{-1} . The interference at 1200 km s^{-1} is found in practically all scans (positive or negative). The final shape often resembles real HI-profiles which may be interpreted as erroneous detections. Moreover, detections of weaker real galaxies within that velocity range are impossible.

Panel *d* shows 2 detections within one beam in the densely populated GA-region, whereas in panel *c* only the feature at 5100 km s^{-1} results from the detection of a massive GA-galaxy; the stronger signal at 4450 km s^{-1} is due to interference.

The interference at 8300 km s^{-1} (panel *f*) constitutes a true problem. Unstable in time and strength, it has perturbed about half of the observations in the higher velocity range. Its strength – sometimes over 10 Jy – causes ringing and baseline wiggles and precludes detections of galaxies in a broad velocity range. This makes an analysis of the detection rate statistics and especially the volume completeness function of the MB ZOA-survey extremely hard.

Still, it can be maintained that the H I-observations recover obscured galaxies deeper in the obscuration layer compared to optical spectroscopy; a natural extension into the fully obscured region will be the MB ZOA-survey. The relatively high detection rate of obscured low-latitude galaxies ($5^\circ \lesssim |b| \lesssim 10^\circ$) forecasts quite a success rate for the MB ZOA survey ($|b| \leq 5^\circ$) – with more than one detection per beam in high-density areas (*cf.*, Fig. 2*a* and *d*).

4 Uncovered Structures and the Cluster Abell 3627

The new redshifts along with published redshifts in adjacent regions evidence the following structures:

The Hydra and Antlia clusters are not isolated clusters, but part of a filamentary structure which can be traced from Hydra through Antlia (*cf.*, Fig. 1), across the Galactic Plane to $(\ell, b) = (283^\circ, -10^\circ)$, thus constituting a major structure in the nearby Universe ($> 35^\circ$ at a median recession velocity of only 2800 km s^{-1}). It seems more a filamentary structure, consisting of spiral-rich groups and clusters, rather than a supercluster.

The prominent galaxy overdensity in Vela is part of a previously unrecognized shallow, large-scale, overdensity centered on $\sim 6000 \text{ km s}^{-1}$. The independent predictions of a supercluster at this position and distance by Hoffman (1994) and Saunders *et al.* (1991) indicate that it could be quite massive.

The redshifts in the cluster A3627 ($< v > = 4882 \text{ km s}^{-1}$ for 131 reduced to date) put this cluster near the center of the Great Attractor in velocity space. The mass estimate from its velocity dispersion ($\sigma = 903 \text{ km s}^{-1}$) is that of a rich cluster ($5 \cdot 10^{15} \mathcal{M}_\odot$). Its other cluster properties – predominance of early-type galaxies at the center, its core radius $R_c = 10'4$ and its central density $N_o = 800 \text{ gal/}\square^\circ$ all are consistent with this being a rich massive cluster (Kraan-Korteweg *et al.* 1996). It even has, like Coma, two dominant central cD-galaxies (*cf.*, Fig. 3).

Rich massive clusters generally are strong X-ray emitters and were identified early on with the X-ray satellites (Einstein, HEAO, Uhuru). Despite dedicated searches and the fact that the hard X-ray band is hardly affected by H I-absorption, A3627 had never been identified in X-ray (Jahoda & Mushotzky 1989, Lahav *et al.* 1989). We therefore studied the ROSAT PSPC data of this cluster (Böhringer *et al.* 1996) and found that A3627, with an X-ray luminosity of $L_X = 2.2 \cdot 10^{44} \text{ ergs}^{-1}$, is in fact the 6th-brightest X-ray cluster in the ROSAT All Sky Survey. Moreover, the independent mass estimate from the X-ray data is consistent with the virial mass.

Fig. 3 displays the X-ray contours (Böhringer *et al.* 1996) superimposed on an image of the central part of the cluster. The X-ray provides interesting insight into the cluster morphology. The X-ray center is offset from the center of the cluster, the strong radio source PKS1610-60.8, one of the two cD galaxies. The latter coincides with the second central X-ray peak. The X-ray emission is not symmetric but extended towards the SE (left-bottom) corner. Subtracting a spherical symmetric model leaves a residual component (*cf.*, right panel). This subcluster contains the wide-angle-tail radio galaxy PKS1610-60.8 whose large radio lobes of 8 arcmin ($\sim 210 \text{ kpc}$)

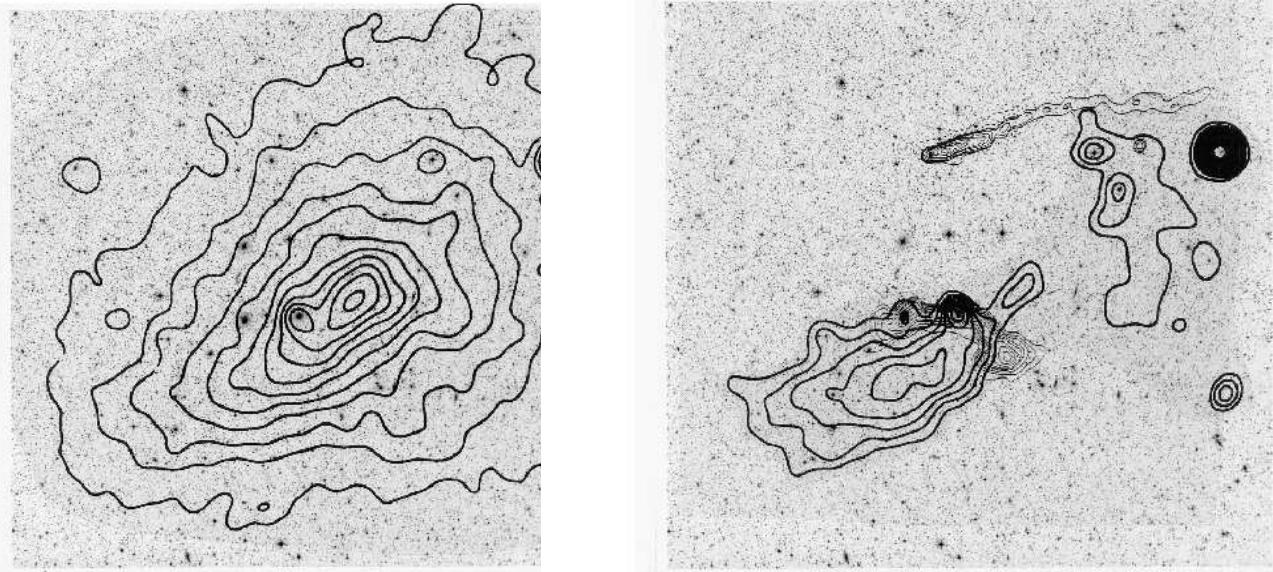


Figure 3: The central part ($56' \times 56'$) of the cluster A3627 as reproduced from field 136 of the IIIaJ copy of the ESO/SRC survey. Superimposed in the left panel are the X-ray contours from the ROSAT PSPC observations; the right panel shows the residual X-ray contours after subtraction of a spherical component, and the 843 MHz radio continuum emission of the wide-angle tail radio galaxy PKS1610-60.8 and the head-tail radio-source B1610-60.5. The strong X-ray point-source (top right corner), a cluster galaxy, is a Seyfert 1 (Woudt *et al.* 1996).

have a bending angle of 45° . The contours of the radio emission (Jones & Mc Adam 1992) are drawn onto the X-ray subgroup as well. Note the alignment of the subclump with the radio emission. The redshift data are yet too sparse to allow a kinematical analysis of this cluster, however, the redshifts in the subclump tend to be higher, suggesting that this subgroup is in front of the main cluster and falling towards it.

The emission from the radio galaxy B1610-60.5 (Jones & Mc Adam 1992) has been drawn into the right panel of Fig. 3 as well. It is one of the longest known head-tail galaxies (26 armin, ~ 710 kpc). The radio emission aligns over nearly its full extent with the 3rd contour of the main X-ray component. The lack of distortion of the radio lobes of both radio galaxies and the compactness of the subclump imply that the suspected merger must be in an early stage. Forthcoming ATCA HI-synthesis observations will allow deeper insight into this cluster.

The cluster A3627 most likely is the previously unidentified core of the Great Attractor over-density. The mass excess of the GA is presumed to arise within an area of radius of about 20-30 Mpc (Lynden-Bell *et al.* 1988). This actually matches the emerging picture from our observations quite well. A3627 seems the center of an apparent “great wall”-like structure, similar to Coma in the (northern) Great Wall: a broad filament reaches from $(\ell, b, v) = (335^\circ, -25^\circ, \sim 4500 \text{ km s}^{-1})$ over the GA region towards $(295^\circ, +5^\circ, \sim 5500 \text{ km s}^{-1})$. Whether it merges into the Vela-supercluster at $(280^\circ, +6^\circ, \sim 6000 \text{ km s}^{-1})$ is not yet certain.

5 Prospects for the Multi Beam ZOA-Survey

The optical deep galaxy survey has reduced the gap of the ZOA and revealed many interesting extragalactic large-scale structures. However, the innermost part of the southern Milky Way remains fully obscured. Here, the MB ZOA-survey will at last allow a view of that area of the

extragalactic sky.

The effectiveness of H I-observations of partially obscured galaxies at low latitudes substantiate the high expectations for the MB ZOA-survey. This survey will trace the above discovered structures in full detail - and also delineate the nearby, dynamically important voids. The Hydra-Antlia extension can be followed even across the inner part of the ZOA. An obscured dominant component might still reveal this structure to be a supercluster. The little studied Vela supercluster can be traced. The mapping of the central part of the GA can be completed, revealing whether it merges with the Vela supercluster or bends back towards the Centaurus clusters. The extent and mass of the nearby Puppis cluster ($245^\circ, 0^\circ, \sim 1500 \text{ km s}^{-1}$, Lahav *et al.* 1993) can be assessed and the extent of the Ophiuchus cluster close to the Galactic bulge at $\sim 8000 \text{ km s}^{-1}$ (Wakamatsu *et al.* 1996) and its connections to other supercluster traced. Other important structures, not yet suggested from optical surveys can be mapped in the deepest layers of obscuration.

These revelations all will lead to a better understanding of the galaxy distribution, the underlying mass distribution and the dynamics of the local Universe.

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